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The BMAP-Tracker Experiment

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The infrared sensor used in the ~~Navy's~~ Background Measurements and Analysis Program (BMAP) was mounted on an optical tracker ~~at the Naval Research Laboratory~~ to monitor commercial aircraft entering and leaving National airport. The experiment demonstrated the capabilities of the tracker-sensor combination and generated data that were used to test a Fourier technique for frame registration. The technique is shown to be effective in preparing data for a frame differencing signal processor to detect moving targets.

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THE BMAP-TRACKER EXPERIMENT

1) Introduction

One goal of the Background Measurements and Analysis Program (BMAP) is to generate an infrared (IR) database for testing IR target detection/clutter rejection algorithms. The BMAP radiometer has been deployed on ground-based and airborne platforms to collect a wide variety of IR data.[1]

In this experiment the BMAP radiometer was installed on an NRL-developed optical tracker to observe aircraft entering and leaving National Airport. The exercise generated a set of radiometric aircraft signatures against real backgrounds with accurate aircraft range and heading information provided by the FAA. The data have been used to test a frame registration and frame differencing algorithm.

2) Equipment Description

The optical tracker (Figure 1) is an elevation-gimbaled, 0.8 meter telescope mounted on a rotatable base. It uses TV cameras (shown in Figure 1) and video signal processing to track a moving target. Table 1 lists the tracker's capabilities.

The BMAP sensor (owned by Raytheon Co. and operated under contract by the Navy) is a dual-band, calibrated, scanning radiometer. It uses refractive optics and two 16-element linear detector arrays to cover the 3-5μ (MWIR) and 8-12μ (LWIR) spectral regions. Detailed specifications for the sensor are shown in Table 2. The sensor forms an image (in each waveband) by scanning the detector arrays horizontally

Manuscript approved April 11, 1988.

1. Lucke et al, "The Navy's Infrared Background Measurements and Analysis Program", Proceedings of IRIS Specialty Group on Targets, Backgrounds and Discrimination; FEB. 1986

across the scene. Detector elements, stacked vertically, form 16 horizontal lines per image. The detectors' outputs are sampled 3.44 times per dwell, substantially exceeding the nominal Nyquist rate of twice per dwell, appropriate for matched optics (i.e., the blur circle diameter equals the detector width). Note that the vertical direction is under-sampled by a factor of two because the detector elements do not overlap.

For this experiment, the BMAP sensor was mounted in the telescope barrel of the tracker and boresighted to the video cameras (Figure 1). The tracker and sensor were located at the southwest corner of NRL from June 9 to July 10, 1986. Measurements were made on several days, but only on one day, July 3, were data recorded of aircraft in highly structured (therefore interesting) cloud background scenes. A total of 1937 frames of data were recorded on this day between 1233 and 1428 hours, tracking 11 departing flights. The aircraft were headed north on takeoff, then turned west and south.

3) Phase Correlation Approach to Picture Registration

The tracker data were used to test a frame registration and differencing algorithm. Frame differencing (subtracting one picture from another, pixel by pixel) is an effective target discriminator when a sequence of pictures contains a target that moves with respect to a motionless background scene because only pixels containing the target are non-zero in the difference frame. When the background moves during the picture sequence, the pictures must be aligned with respect to the background features (picture registration) before computing the difference.

The algorithm used to compute the misalignment of the scene between two pictures, phase correlation, exploits the fact that the displacement of the scene can be determined from the phase of the cross power spectrum of the pictures.[2] (An extensive analysis of phase correlation can be found in reference [3].)

The phase correlation matrix, d, is computed for two pictures, g_1, g_2 from the following equation:

$$d = F^{-1}\left[\frac{G_1 G_2^*}{|G_1 G_2^*|}\right]$$

where:

G_i = two dimensional FFT of image g_i, i=1,2
G_i^* = complex conjugate of G_i
F^{-1} = inverse Fourier transform

When g_1 and g_2 are pictures of the same scene, but are misaligned by (m,n) samples, the phase indicator function (the surface defined by the values in the d matrix) forms a peak at the (m,n) element in d. If g_1 and g_2 are aligned, there will be a peak at (0,0). For partially overlapping pictures, the phase indicator has many non-zero values (noise) and a diminished registration peak. Phase correlation will misregister pictures if the noise-produced peaks are larger than the registration peak. Peak height is reduced, for example, when the misregistration between scenes is not an integer number of samples, and the peak may be spread out over as many as four elements in the d matrix. (The location of the peak is found by searching for the maximum d-matrix value and then interpolating through the maximum and neighboring samples with a function of the form (sinx)/x.[3] The registration point is then given by the maximum value of the interpolated

2. Kuglin and Hines, "The Phase Correlation Image Alignment Method", Proceedings of the 1975 Int. Conf. on Cybernetics, (IEEE), 1975

3. McHugh, Schaum, "New Methods of Image Registration", 36th National IRIS ;26MAY,1988

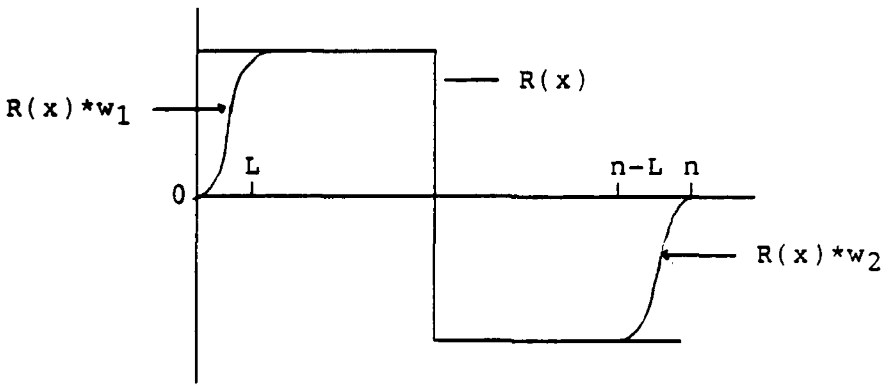
curve.) Other effects that can cause reduced peak height or false peaks are discussed below.

A scanning sensor produces a frame of data by scanning the detector(s) across the scene with a scan mirror. In a tracker/scanner system, the effective scan rate of the scanner is the sum of the scan mirror's intrinsic rate and the component of the tracker's angular rate in the scan direction. Any variation in the tracker's angular rate between frames (or during a frame) will change the size of the sensor's footprint, making scene features appear to be stretched or compressed from frame to frame. Spatial distortions of this type cause different parts of the scene to move by different amounts between frames. This can confuse phase correlation which is only good for measuring rigid translations of scene features. Stretching of the scene by several samples in the scan direction was observed in some of these data, resulting in poor performance of the registration algorithm. In an operational tracker/scanner combination, the tracker's rate may need to be integrated into the scanning rate of the sensor to avoid these spatial distortions.

Another problem arises from the way Fourier analysis treats a function defined only over a finite domain. Phase correlation, based on the Discrete Fourier Transform, assumes that each frame of data under consideration is one complete cycle of an infinitely-extended function. If, for example, the left side of a scene has a substantially higher intensity than the right side, the result is a cyclic Fourier function with a jump discontinuity. Since this jump does not move from one picture to the next (it is always at the edge), the phase indicator function registers a peak at (0,0) (in addition to the real registration peak) indicating, erroneously, that there was no scene shift between pictures.

This problem is dealt with by multiplying the picture data with a function that removes the edge discontinuity in the "Fourier scene" without disturbing the structure in the interior of the picture (see reference 3). Figure 1 demonstrates the method employed, simplified to one dimension:

Figure 1



where:
$R(x)$ = scene radiance with mean removed
n = number of samples across a frame
L = number of samples used for smoothing
$w_1 = .5 * (1 - \cos(i\pi/L))$, $i = 0,1,\ldots L$
$w_2 = .5 * (1 - \cos((N-i)\pi/L))$, $i = n-L,\ldots n$

If the one dimensional scene, R(x), is featureless except for a step somewhere near the middle of a frame, there is a dramatic intensity difference between left and right edges. When phase correlation is applied to two pictures sampled from this scene, the phase indicator function will have two peak values of equal intensity, one corresponding to the displacement of the central feature between the two frames, and another, showing no displacement, caused by the intensity difference between left and right edges. Since the peaks are of equal intensity, phase correlation has no way of discriminating the real registration peak from the artifact. Using the modified scene, $R(x)*w$, the amplitude of the edge-produced peak is less than the registration peak, allowing the registration point to be found unambiguously. The extent to which this "edge-effect peak" is removed is a function of L, the number of samples affected by the weighting function, and must be optimized so that the weighting will not alter features over too large a part of the scene. The values $L = 2$ in the vertical direction ($n = 16$), and $L = 58$ in the horizontal direction ($n = 360$) worked well for these data.

Another problem arises when phase correlation tries to determine large displacements (more than half a picture) between two pictures. For two pictures with $n \times m$ picture elements (pixels) each, there are $2n \times 2m$ distinct shifts in scene content that could occur between the two: the common scene element in the first picture might be shifted anywhere from 0 to $\pm n \times \pm m$ pixels in the second. However, the phase indicator function has only $n \times m$ unique values because there are only $n \times m$ unique cyclic shifts in the Fourier scene. For non-cyclic shifts the phase indicator function is ambiguous. A peak at the i^{th} element could mean a shift of i samples in one direction or (n-i) samples in the opposite direction. To avoid this ambiguity the size of each picture analyzed is made four times as large as the original picture by stitching each picture onto itself -right edge to left and top to bottom (after the edge-smoothing)- producing a phase indicator that can uniquely describe $2n \times 2m$ shifts. This method is simple and effective but somewhat more computer-intensive than an iterative approach described in reference 3.

4) Frame Difference Analysis

Once phase correlation determines the amount of image misalignment, the pictures must be realigned by that amount before computing their difference. In general, this requires both a whole number sample shift and a fractional shift. To do the fractional shift, it is necessary to reconstruct the scene between samples. Linear interpolation between adjacent samples in the scan direction is fairly accurate because the data are oversampled in that direction. In this paper we are not overly concerned with sub-pixel registration accuracy, so linear interpolation in the vertical (cross-scan) direction is adequate even though the vertical direction is under-sampled. A more complicated method such as cubic convolution (also discussed in reference 3) could be used to improve the accuracy of sub-pixel reconstruction, especially in the cross-scan direction.

The frame registration-frame differencing algorithm described above was run in a "hands off" mode on several sequences of tracker data with the results shown in Figures 3-7. In each figure there are four greyscale images generated on an 8 bit Gould/Deanza image processor. The two input data frames are shown at the top of each figure with IRIG time (day: hour: minute: second) displayed above the frame and the identifying frame number and IR band (MW,LW) on either side. The third image is that part of the second frame (resampled) that is in common with the first. The last image shows the absolute value of the difference frame. The absolute value is used for display purposes so that a zero in the difference equals black (not grey). The greyscale range is self-scaled in each image to emphasize details of the scene structure.

The results show that phase correlation can register images with very large offsets, but that the offsets must be purely translational for the algorithm to be an effective clutter-canceller. In figure 3, the two adjacent bright spots (a positive and a negative peak) in the difference frame are the characteristic moving target indicator (MTI) of the frame difference algorithm. In figure 4 the aircraft is made conspicuous by the difference processor, but it shows up as only a single bright spot in the difference frame because it is behind the clouds in frame 411. In figure 5 the presence of strong background clutter in the difference frame is a result of the scene stretching discussed in section 3. This causes the sharp edges of the background structure to "leak" through the differencing processor. Figure 6 demonstrates phase correlation's ability to register large offsets (more than half a picture). In this case, the background clutter in the difference frame is brighter than the aircraft because of scene stretching. (The aircraft is just emerging from the cloud edge in frame 307; vertically it is centered in the picture.) Figure 7 demonstrates phase correlation's ability to register pictures where there is substantial scene motion in two directions. Here again the aircraft appears in only one frame because it has just emerged from behind a cloud and there is significant clutter in the difference frame due to scene stretching.

5) Conclusion

The tracker experiment demonstrated the operation of NRL's tracker-sensor combination and produced an IR data set useful in evaluating target-background discrimination techniques. Tracker accelerations that occurred while taking data caused distortions in the scene beween frames. In an operational tracker-sensor system, the tracker's rate should be coupled to the scan mirror's intrinsic scan rate to avoid these distortions.

A frame registration and frame differencing algorithm was tested using the tracker data set. The results show that it is possible to register pictures using phase correlation, even for very large scene offsets. When the scene moves rigidly between pictures, phase correlation is an effective precursor to a frame differencing signal processor.

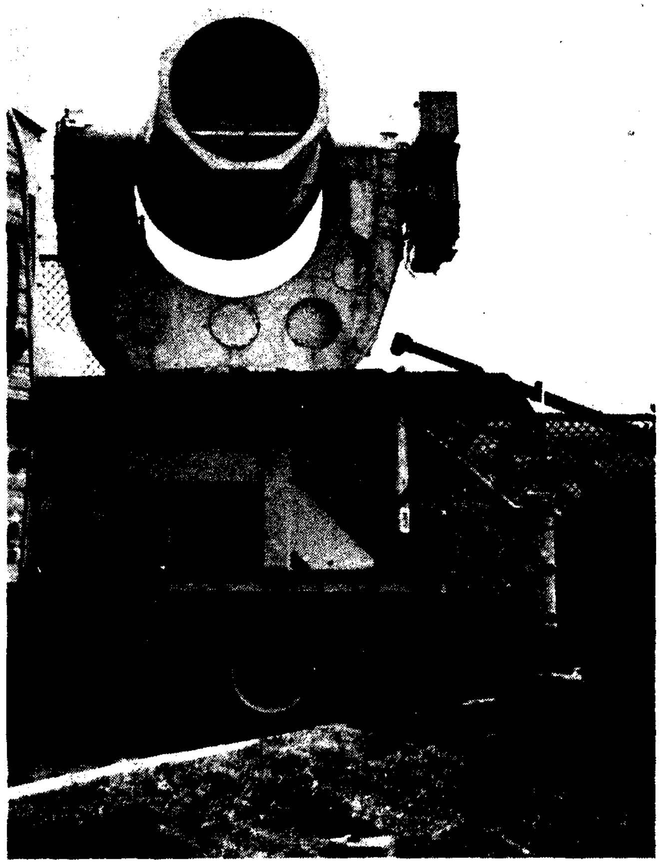


FIGURE 2
The optical tracker shown with the BMAP sensor mounted inside the telescope barrel. The video cameras used for tracking are housed in pods to the right of the gimbal axis.

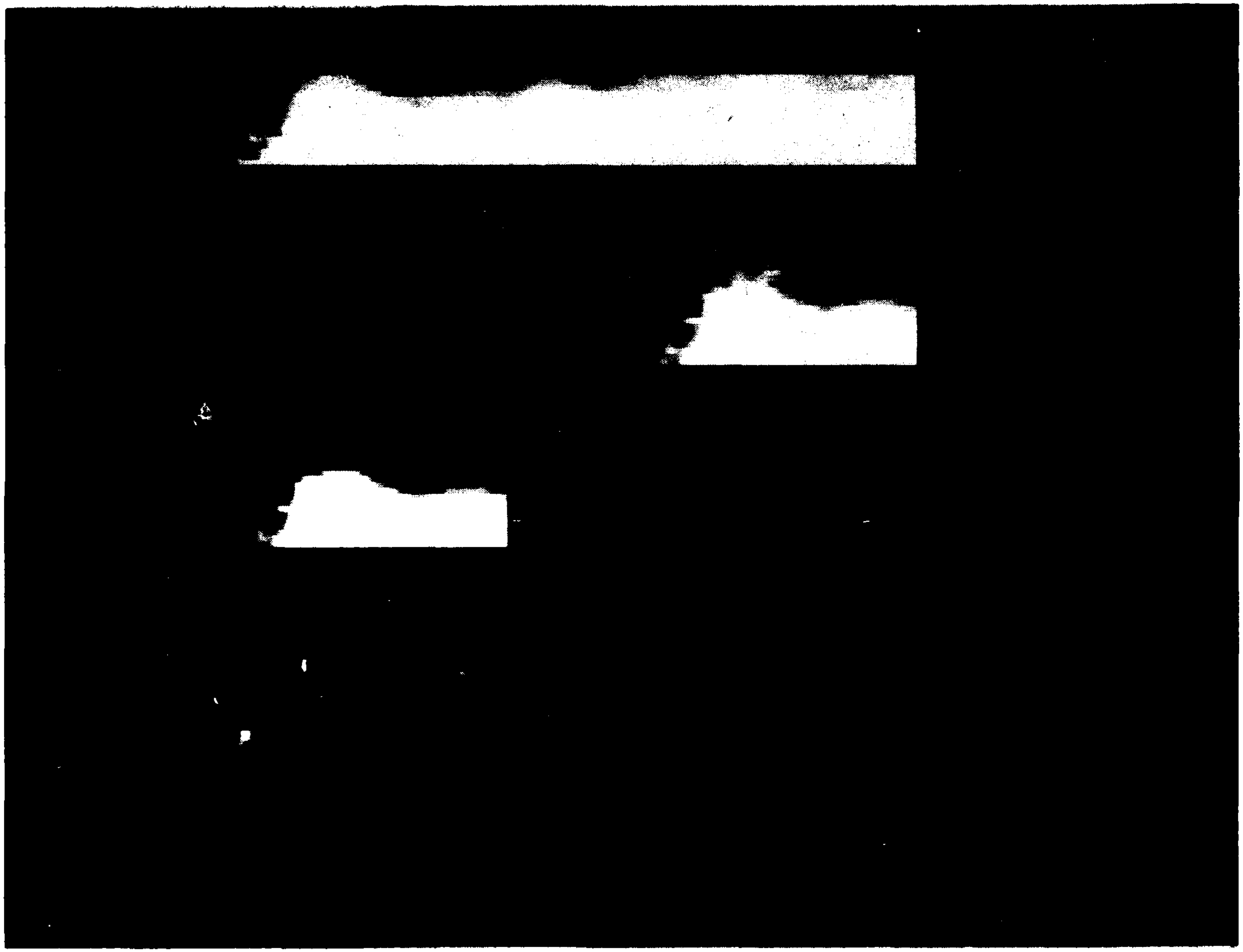


FIGURE 3

Aircraft: Boeing 737, Altitude: 5300 feet, Range: 12 nautical miles, Band: longwave, Sample Offset: 122.5, Channel Offset: 0.3

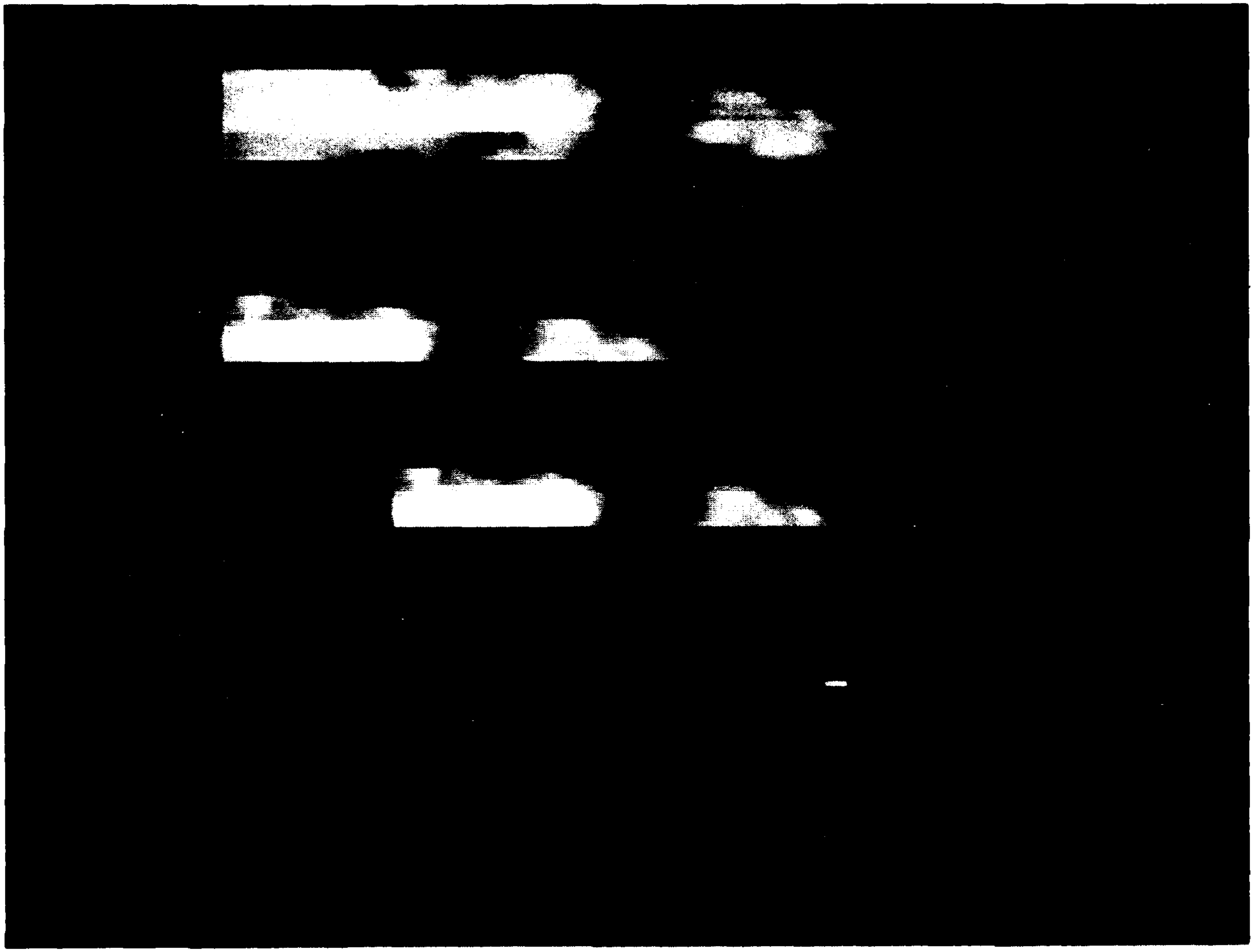


FIGURE 4

Aircraft: Boeing 737, Altitude: 5100 feet, Range: 11 nautical miles, Band: longwave, Sample Offset: 2.5, Channel Offset: 0.5

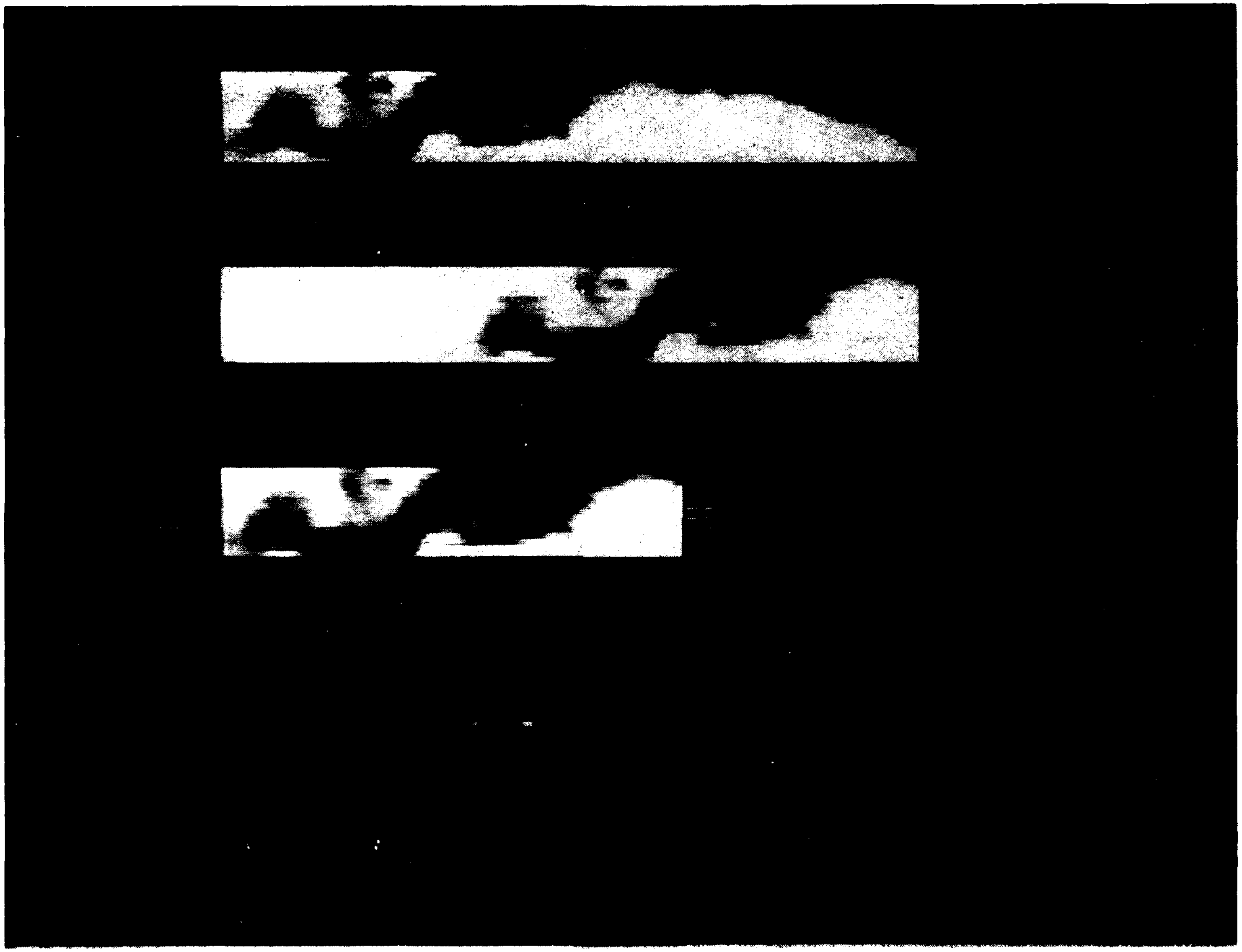


FIGURE 5

Aircraft: Boeing 727, Altitude: 5500 feet, Range: 13 nautical miles,
Band: longwave, Sample Offset: 33.5, Channel Offset: 0.4

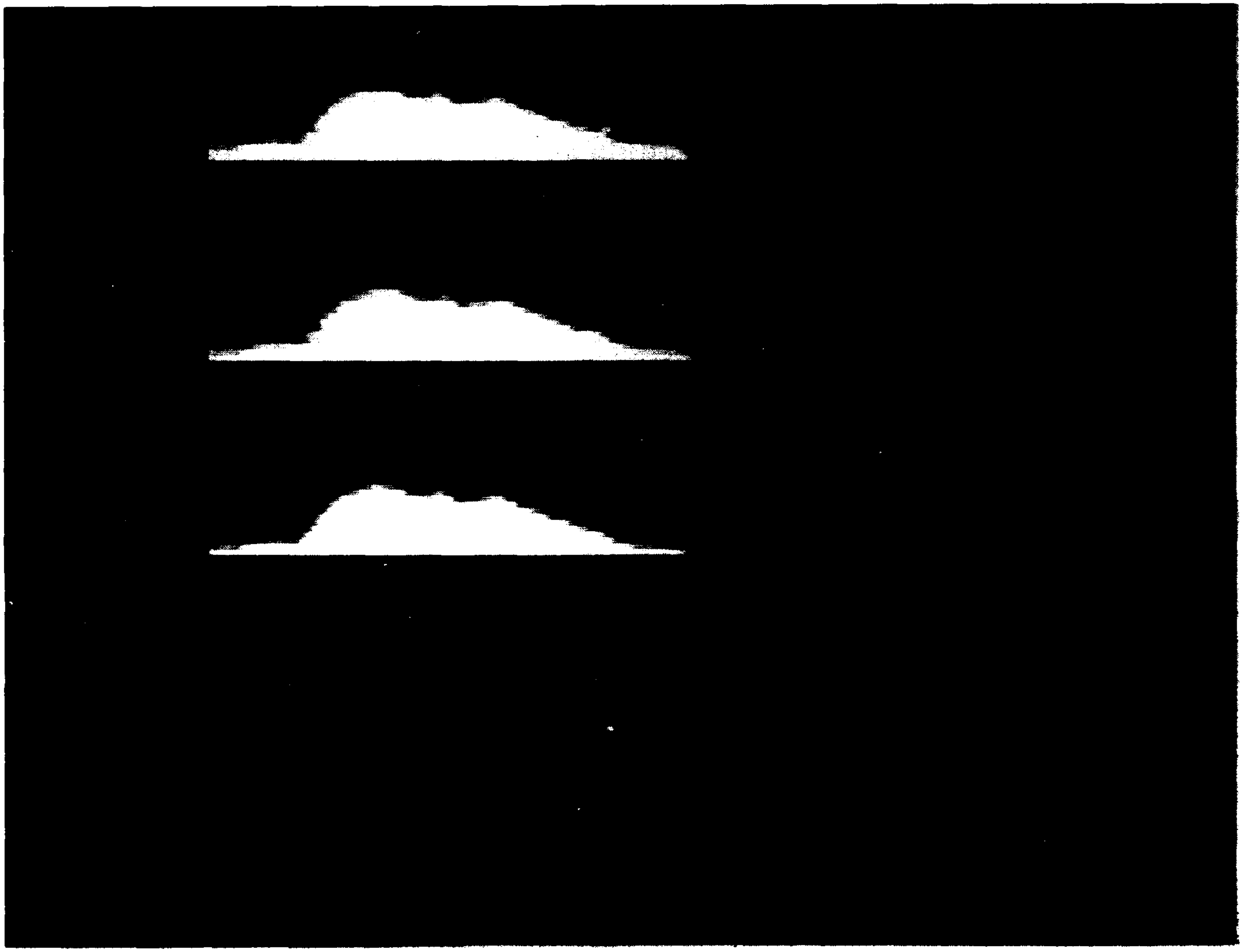


FIGURE 6

Aircraft: Boeing 727, Altitude: 5500 feet, Range: 13 nautical miles,
Band: longwave, Sample Offset: 208.5, Channel Offset: 0.5

FIGURE 7

Aircraft: Boeing 727, Altitude 4700 feet, Range: 12 nautical miles,
Band: midwave, Sample Offset: 85.4, Channel Offset: 5.6

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